Investigating gaze interaction to support children's gameplay

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Research paper

Investigating gaze interaction to support children's gameplay

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ABSTRACT

Gaze interaction has become an affordable option in the development of innovative interaction methods for user input. Gaze holds great promise as an input modality, offering increased immersion and opportunities for combined interactions (e.g., gaze and mouse, touch). However, the use of gaze as an input modality to support children's gameplay has not been examined to unveil those opportunities. To investigate the potential of gaze interaction to support children's gameplay, we designed and developed a game that enables children to utilize gaze interaction as an input modality. Then, we performed a between subjects research design study with 28 children using mouse as an input mechanism and 29 children using their gaze (8–14 years old). During the study, we collected children's attitudes (via self-reported questionnaire) and actual usage behavior (using facial video, physiological data and computer logs). The results show no significant difference on children's attitudes regarding the ease of use and enjoyment of the two conditions, as well as on the scores achieved and number of sessions played. Usage data from children's facial video and physiological data show that sadness and stress are significantly higher in the mouse condition, while joy, surprise, physiological arousal and emotional arousal are significantly higher in the gaze condition. In addition, our findings highlight the benefits of using multimodal data to reveal children's behavior while playing the game, by complementing self-reported measures. As well, we uncover a need for more studies to examine gaze as an input mechanism.

1. Introduction

Games are an area open to novel input devices aiming to offer engaging and joyful experiences to players. Nowadays, the proliferation of affordable and advanced eye-tracking technology enables the use of gaze interaction in games and places it as an interaction mechanism that enhances the gameplay experience (Ramirez Gomez & Gellersen, 2019). In addition, popular games like Assassins Creed Rogue released a gaze interaction version. Also, emerging virtual reality (VR) and augmented reality (AR) devices include eye-tracking, like the FOVE VR headset. Furthermore, eye-tracking companies have released eye-tracking devices that are dedicated to gaming (e.g., https://gaming.tobii.com/) and are compatible with more than 140 games. Reflecting on the growing research and the promising future of gaze interaction in games, Ramirez Gomez and Gellersen (2019) and Velloso and Carter (2016) proposed the existence of the *"EyePlay"* research community, as a separate and emergent field within the HCI community based on Turner's et al. (Turner, Velloso, Gellersen, & Sundstedt, 2014), term *"EyePlay" referring to playful experiences that take input from the eyes.*

As an input modality, gaze has several advantages; eye movement is fast, easy to learn, decreases fatigue from physical movement and is available for disabled users, and interaction appears to be a natural way of selecting (Sibert & Jacob, 2000). So, users can look at specific parts of the screen or follow specific gaze patterns (e.g., focus, transition) and perform relevant and predefined actions (depending on the game design). Several studies include gaze interaction in different types of games, including puzzles (Gowases, Bednarik, & Tukiainen, 2008), shooting games (Isokoski, Hyrskykari, Kotkaluoto, & Martin, 2007), chess (Špakov, 2005), the well-known Super Mario Bros platform game (Munoz et al., 2011), and *Eyequitar* (controlling a paddle game) (Vickers, Istance, & Smalley, 2010). Furthermore, gaze interaction improves the accessibility of the game by replacing or complementing the different game controllers (Isokoski, Joos, Spakov, & Martin, 2009; Isokoski & Martin, 2006; Smith & Graham, 2006). For example, gaze can be used as a single input for games or combined with voice (O'Donovan, Ward, Hodgins, & Sundstedt, 2009) or head movement (Sidenmark & Gellersen, 2019). In addition, many studies report that the resulting increase

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in sense of immersion alters the gameplay experience and makes it more enjoyable (Smith & Graham, 2006).

Despite extensive research on the use of gaze as an input modality during gameplay (Velloso & Carter, 2016), there are very few studies, to the best of our knowledge, investigating if and how gaze input modality can be employed in Child–Computer Interaction (CCI) research to support children's experience, leaving this area under-explored. Current research has been focusing on adult gameplay interactions with gaze, and typically has a wide range in participants' age (Isokoski et al., 2007; Nacke, Stellmach, Sasse, & Lindley, 2010). Children's gaze has been studied as an input modality in a very specific group of children (no functional use of their arms and legs), for a low-interactivity tasks (typing, reading and drawing) (Hornof & Cavender, 2005) and examined as a gaze-aware agent beneficial for early childhood learners (Akkil, Dey, & Rajput, 2017). Gaze provides the potential of a promising interaction modality for children, offering interesting and engaging gameplay experiences. Going beyond well accepted interaction modalities (e.g. mouse, touch, tangibles) and styles (e.g. point and click, drag and drop) for children, which have been evaluated and introduced during the last years (Besançon, Issartel, Ammi, & Isenberg, 2017; Holz & Meurers, 2021; Inkpen, 2001), the motivation is to investigate the seamless and hands-free interaction of gaze. This can lead to introduction of another interaction modality in games that may provide more intuitive and immersive controls and thus foster a better experience to children playing game for entertainment or educational purposes. Further exploration of gaze as an input modality, also allows us to better understand its potential and enhance its use in different contexts and design interfaces for children (Cockburn, Kristensson, Alexander, & Zhai, 2007).

To this end, the aim of this paper is to explore the use of gaze as an interaction modality in games played by children and understand their experience in terms of performance and perceptions, as well as their affective and behavioral processes. Therefore, we are focusing on the following research question (RQ): *What is the potential of gaze as an interaction modality to support children's gameplay?*

To respond this ambitious question, we designed and developed a game that enables children's use of gaze interaction as an input mechanism and conducted a between subject's study (mouse or gaze as an input) with 57 children in total (8–14 years old) who played the game using either gaze or mouse as input. During their gameplay, we utilized sensing technology (i.e., physiological data, facial videos) which allowed the collection of physiological data from children's interaction with the two different versions of the game (i.e., gaze, mouse inputs). In addition, we collected children's responses with a post-task attitudinal survey. Our intention is not to necessarily replace other interaction modalities; rather, we aim to motivate and highlight the benefits and potential of using gaze as an alternative interaction modality for children.

2. Related work

2.1. Gaze interaction in games

Gaze as an interaction modality has received significant attention in HCI research over the past three decades (Majaranta & Bulling, 2014). One of the main focuses has been the exploration of interaction capabilities associated with gaze as an input modality (e.g., the Midas touch, the ability to select small objects, and performing mouse-friendly functionalities such as zooming and scrolling Bates & Istance, 2002; Jacob & Karn, 2003; Skovsgaard, Mateo, Flach, & Hansen, 2010). To investigate the strengths and weaknesses of gaze as an input modality, previous works have conducted controlled experiments that compare gaze as an input modality with the most commonly used methods, such as mouse (e.g., Sibert & Jacob, 2000). While substantial progress has been made during the last years, to date there is a lack of research centered on the use of gaze interaction as a modality for supporting children as end-users.

The use of gaze as a input interaction provides compelling advantages (e.g., fast and effective), and recent advances in eye tracking technology and research have made gaze more practical and popular (Jacob & Stellmach, 2016), especially in highly interactive applications, such as games (Nacke et al., 2010). Moreover, gaze stands as an alternative input mechanism for people with and without disabilities. In particular, *EyeDraw* is a software that enables children with severe motor impairments to draw using their gaze (Hornof & Cavender, 2005). From a player's perspective, using the eyes appears to be intuitive and quick for pointing, as people automatically look at the preferred interactive objects (Jacob, 1990; MacKenzie, Kauppinen, & Silfverberg, 2001). Nevertheless, use of the eyes may cause undesired actions when playing a game, causing distractions, frustration and inefficiency. The most notable problem observed, is that eye movements have the characteristic of being always active, so the user cannot stop controlling an interface when looking at it. This issue, known as the "Midas" touch problem (Jacob, 1990), occurs when the user's gaze actuates everything that reacts, without necessarily wanting to. To confront this problem, Jacob (1990), suggested using gaze behavior together with another action, either external, such as mouse click or from gaze, such as fixating on an object for a while (i.e., focus).

Gaze-based gameplay has been investigated by several studies using different gaze-interaction mechanisms as an input. During the "always-on" interaction in 2D environments, gaze can be used explicitly to continuously control different parameters, like a paddle in *Eyeguitar* (Vickers et al., 2010) and *Breakout* (Dorr, Böhme, Martinetz, & Barth, 2007) games, or a character (Nacke, Stellmach, Sasse, Niesenhaus, & Dachselt, 2011). This interaction may force the player to be immersed as gaze is the only and way of interaction. Other mechanisms include gaze-based selection, which can happen by staring at an object (dwell-time) or by performing other eye gestures like blinking, discrete saccades or gliding (Špakov, 2005). For instance, Gowases et al. (2008) implemented dwell-gaze selection for a puzzle game. The player's gaze needed to fixate on the preferred tile for one second to actuate it. Vidal, Bulling, and Gellersen (2013) used eye pursuit movements in a flog game, where users selected flies (moving targets) that appeared on screen. The idea of this game is based on the fact that the player's gaze will follow the moving object and result in the same trajectory. Another mechanism is gaze-augmented selection, in which gaze is used in conjunction with a mouse, keyboard or other manual pointing input. An example of this is Cascaded (MAGIC) pointing, in which the eyes are used to place the cursor close to the preferred object and then the mouse input is used to acquire the target (Cockburn et al., 2007). In this way, users moved the cursor faster with their eyes and reported that "magic" was happening, as the cursor followed their intention. In addition, use gaze as an input for games has often been combined with the use of hands, and also head movement or voice for interaction purposes. Sidenmark and Gellersen (2019) introduced the combination of gaze and head movement to provide more flexible and controlled actions for point and select. As an alternative to mouse and keyboard. O'Donovan et al. (2009) examined the use of gaze and voice recognition in the *Rabbit Run* game, where players attempted to exit a warren maze.

Nowadays, gaze interaction is employed in a variety of games offering an extra dimension of interaction to enhance the gaming experience. In mixed reality environments using HoloLens, gaze is one of several integrated interaction methods applied in educational games for children (Wang, Qian, Zhang, Lu, Chen, & Liu, 2019). Examples of games include puzzle games (Gowases et al., 2008), first-person shooting games (Isokoski et al., 2007), *EyeChess* (Špakov, 2005), the known Super Mario Bros platform game (Munoz et al., 2011), *Eyequitar* (controlling a paddle game) (Vickers et al., 2010) and *GazeArchers* (in which two players play against each other using gaze and touch input Pfeuffer, Alexander, & Gellersen, 2016). Velloso and Carter (2016), conducted a survey resulting in five different categories of eye-based game mechanics (navigation, aiming and shooting, selection and commands, implicit interaction and visual effects). Implicit interactions leverage players' attention patterns and other cognitive processes, obtaining information from the environment around them. In this way, it is possible for implicit use of the gaze data to influence game interactions; for example, by creating the possibility to adapt a game based on players' visual attention, affect social interactions and create responsive environments (Velloso & Carter, 2016). Akkil, Dey, and Rajput (2017) explored the potential of gaze-based interaction for educational applications for children. One of their studies (Akkil, Dey, Salian, & Rajput, 2017) proposes the use of a gaze-aware adaptive agent who shows emotional response to young learners while teaching them about fruits and vegetables during their gameplay interaction.

2.2. Gaze interaction compared to other input modalities

Since one of the oldest comparisons between gaze and mouse (Jacob, 1990), showed that selection through gaze can be as fast as selecting with the click of a button, many researchers have investigated the differences between gaze input and other types of interaction during gameplay. While comparing the use of mouse/keyboard and gaze/voice interaction in terms of users' enjoyment from the *Rabbit Run* game (O'Donovan et al., 2009), no significant difference was found. However, mouse/keyboard was ranked as easier and requiring less effort while playing. In another study, the authors used a modified device for the popular on-line game *World of Warcraft* game, allowing different modes of gaze interaction to imitate mouse and keyboard interactions (Istance, Hyrskykari, Vickers, & Chaves, 2009). Most participants reported that using gaze to control a character's change in direction was difficult.

In the same vein, Bednarik, Gowases, and Tukiainen (2009) examined the effect of three interaction mechanisms: dwell-time, gaze-augmented and mouse interaction on performance, problem-solving strategies and user experience in a problem-solving game. Their results showed that users in the gaze-augmented interaction performed more favorably in some of the problem-solving measures and were more immersed in the game, followed by users of dwell-time interaction. In a study testing the same interaction modes in a puzzle game, Gowases et al. (2008) found that dwell-time interaction was the most difficult method from three conditions to control an interface, but users recognized it as immersive. In a more advanced comparison, Pai, Dingler, and Kunze (2019) used different input methods in VR technology, including gaze together with electromyography (EMG). Comparing five different input modalities: gaze with fore-arm contractions, Xbox gamepad, dwelling time (not from gaze), gaze-dwell and motion (i.e., gamepad tracked in the virtual space) as inputs in the VR environment, they found that the perceived mental workload of the participants in the simple shooting game, was lower in the gaze and EMG condition than in the dwell and gaze condition.

Gaze-based interaction has also been compared to touch input mostly in mobile devices, like tablets. For example, Lankes and Stiglbauer (2016) found that adding gaze input in an AR game, results in a better user experience when compared to a touch-only condition. The ''Neon Glider'' (Uludağli & Acartürk, 2018) game introduced a hands-free gaming option, in which players can control the interface with gaze-voice command or touchscreen. Although the findings showed no difference in game performance between the two conditions, players exhibited stronger engagement in the gaze-voice interaction. Their study illustrates the potential of gaze and places it as an acceptable interaction compared to touchscreen in mobile games. Akkil, Dey, Salian, and Rajput (2017) recognized the challenges of the common touch-based interaction when designing applications for children (e.g. the problem of accidental touches McKnight & Fitton, 2010, need for careful positioning of the screen Romeo, Edwards, McNamara, Walker, & Ziguras, 2003), and explored the value of gaze aware agent named ''Little Bear'' in a learning application teaching vocabulary to children. Their results showed that children had longer interaction with the game and improved vocabulary in the gaze aware interaction, when compared to touch.

Overall, due to the relatively large number of studies on gaze interaction in games, there is a clear consensus on the potential of gaze as an input. There is, however, no discussion regarding the users' age or the potential challenges and opportunities for young children.

2.3. Portraying children's experience using multimodal data

Nowadays, the development of advanced technologies has spawned new possibilities of non-invasive and high-quality data capturing devices for example, eye-tracking, wearable sensors, and high accuracy cameras. In addition, growth in data science offers analysis techniques, like machine learning, which enables researchers to capture and analyze various aspects of human behavior. During the last years, collecting multimodal data (MMD) has become more popular in research studies (Crescenzi-Lanna, 2020; Sharma & Giannakos, 2020). Tandem to this, ethical issues have become an important subject of discussions (Crescenzi-Lanna, 2020; Sharma & Giannakos, 2020). MMD allow us to capture the complexity of human interactions, go beyond subjective self-reported behaviors, and offer information from a range of cognitive and non-cognitive processes (Noroozi et al., 2019; Reimann, Markauskaite, & Bannert, 2014). Combining different data coming from a variety of modalities, like videos, physiological and biological sensors and log-data, can provide a rich understanding of the user's actual behavioral, physiological and mental processes that concur during different phases of their actions.

The benefits of MMD have also been revealed from their use for capturing different aspects of children's behaviors. Rahman and Bhuiyan (2015) show the design and development of a prototype system that allows the analysis of physiological signals (e.g. heart rate, skin temperature, skin conduction, bodily motions or postures) from children with special needs for improving their everyday interactions. In another study, Goodwin, Mazefsky, Ioannidis, Erdogmus, and Siegel (2019) found that physiological arousal and motion data, measured by a wearable biosensor, can predict aggressive behavior by children with Autism Spectrum Disorder (ASD).

Different data modalities have been used to unveil children's experience when interacting with technology. For instance, children's gaze was found to portray their learning experience during coding (Giannakos, Papavlasopoulou, & Sharma, 2020; Papavlasopoulou, Giannakos, & Jaccheri, 2017). Eye-trackers were also used from Frutos-Pascual and Garcia-Zapirain (2015) to record children's gaze while solving a set of puzzle games. The aim of their study was to determine the existence of different gaze patterns between high and low performers. Recently, Nizam and Law (2021) also used eye-tracking technology to examine children's interaction strategies with digital educational games from gaze sequence analysis. In another study, Pérez-Espinosa, Martínez-Miranda, Avila-George, and Espinosa-Curiel (2018) explored the levels of interest, engagement and involvement as revealed from children's audio-video recordings during their interaction with a Lego Robot. Another useful source of data is children's facial expressions. Ouherrou, Elhammoumi, Benmarrakchi, and El Kafi (2019) used children's facial expressions to detect their emotions by analyzing seven basic facial emotion expressions (angry, disgust, fear, happy, sad, surprise and neutral) while playing an educational game. In the same vein, Sharma, Papavlasopoulou, and Giannakos (2019) also used videos to extract children's emotions (via facial expressions), and then identified their joint emotional state and its relationship with children's perceived experience.

Overall, MMD collected during interaction with technology allows us to understand children's experience through the lens of their affective and behavioral processes. Related work has found that MMD provides a valuable solution that enables us to unveil rich interactions (Sharma & Giannakos, 2020). Lieberman, Fisk, and Biely (2009) suggest the use of different technologies (e.g., eye-tracking, fMRIs (functional magnetic resonance imaging) of brain activity, facial expression recording) to understand children's emotional, cognitive, social and physical interaction with games, in hopes of leading to better design. Therefore, we can leverage on MMD and consider the trade-offs of its capacities (e.g., explainability of gaze, brain, face, skin) and limitations (e.g., ecology, cost) of the various modalities.

3. Methodology

3.1. Description of the two versions of the game

For our study, we developed a shooting game called Xtreme Yoga which has two different input mechanisms, mouse or gaze input (based on non-intrusive Tobii eye-tracking functionality). In both input version, gameplay is similar, and consists of moving a player-controlled avatar through a two-dimensional level. Other characters (not controlled by the player) in the game are the "knights" that the avatar must be protected from. The knights appear at random and try to kill the avatar by throwing bullets (shooting) which are represented by white and red balls (Fig. 1e). The avatar has three lives and loses life's expectancy when struck by bullets. A game-session ends when all three lives are lost. In addition, the game has a score that increases in relation to the time the avatar stays alive by surviving the bullets (1 point for each bullet survived) and to the knights the player kills. Using either the mouse or their gaze, a player controls a white circle on screen (Fig. 1a). This is the only game element the player controls in the entire game. The avatar can move in all the directions by following the white circle (Fig. 1b). This is one way the player protects the avatar from the bullets, by walking him away from the bullets towards different parts of the screen. Another interaction is moving the circle over top of the avatar. In that way, the circle hovers over the avatar and the circle turns yellow (indicating that it has transformed into a shield); and consequently, the bullets do not harm the avatar (Fig. 1d and f). The third and last interaction of the game is shooting. The avatar can shoot the knights by throwing bullets (represented on screen as white balls) towards to knights. In order to shoot, the avatar must hover over a knight (Fig. 1c). The game ends once the player loses all three lives and a "game over" message is displayed on the screen. Then, the player can see the achieved score and write a unique code, which is an ID for the specific player in the respective section. If the player wants, they may continue with another game session. Therefore, the gameplay is consisted of a combination of the three possible interactions, with an ultimate goal of achieving the highest possible score (i.e., survive for the longest time and kill as many knights as possible).

The player controls the white circle on the screen (and as a result the avatar) using either the mouse or the gaze input modality. Both input conditions have the same game mechanics. The set of rules, instructions and the interface design are minimal to introduce gaze interaction. In the gaze input modality, the player performs all actions with their gaze. More precisely, the avatar moves to different on-screen locations by following the player's gaze (interaction 1), the avatar is shielded when the player hovers over the avatar with their gaze (interaction 2), and the avatar shoots when the player hovers over the knights with their gaze (interaction 3). In the mouse condition, the player performs all actions with the mouse. That is, the avatar moves to different on-screen locations by following the player's mouse (interaction 1), the avatar is shielded when the player hovers over the avatar with their mouse (interaction 2), and the avatar shoots when the player hovers over the knights (interaction 3) with their mouse.

A menu system at the beginning of each session offers the choice of interaction modality, but in both conditions the eye-tracking device is on.

On a general note, we accept that different input modalities do not have the exact same characteristics, abilities or usability and that their advantages and disadvantages relate each time to the goal and the application (Besançon et al., 2017). The same applies in our case, and our choice to compare mouse and gaze input. Many shooting games have used mouse and gaze interactions (Velloso & Carter, 2016).

Driven by our motivation to explore the potential of applying gaze as an input modality, we aimed to keep the game easy to learn, by using minimal, simple game actions, like changing the avatar's location, and shooting. We kept the rules simple and the game mechanics consistent in both interaction modalities in our game. More specifically, to ensure smooth and efficient gaze, rather than use raw gaze data to control the avatar, we leveraged Tobii eye-tracker's ability to consider the area *around* the avatar to trigger its movement (i.e., the movement of the avatar is smoothed as the actual activation happens from a larger area around the avatar). On the other hand, in the mouse condition we only used the affordance of the cursor's pointing movement on the screen and not the click which provided a fine positioning of the avatar. Our choice to use mouse and not touch-based interaction in our game for the comparison was driven by several reasons. First, touch is mostly popular with mobile devices for children's applications (Akkil, Dey, Salian, & Rajput, 2017), while in our case we used a desktop computer. Second, one difficulty that children face with touch interaction is moving their fingers across the screen at a constant speed (Lu & Frye, 1992), which in our case would possibly cause problems and tire the children, since as movement is an essential action to be performed in the Extreme Yoga game. In addition, in our game, touch interaction would hide the avatar with the child's finger while keeping a constant contact on screen to move the avatar. This would also hinder the fast movement that mouse and gaze offer. Lastly, adding a multitouch interaction to the game, for example moving the avatar with one touch and killing the knights with another, would have caused latency in the children's reactions.

3.2. Research design

The study follows a between-subjects research design, with the interaction modality (i.e., gaze or mouse input) as a testing factor. Acknowledging the advantages and disadvantages of between-subjects design in HCI research (Hornbæk, 2013), we have chosen this design because it is simple for participants,

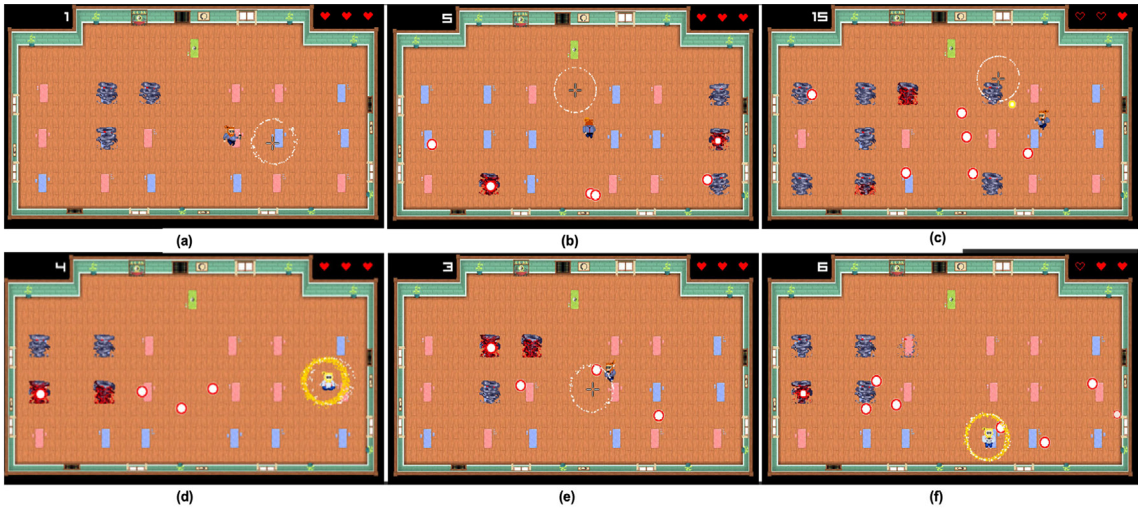

Fig. 1. (a) Starting point of the game. (b) The avatar follows the circle. (c) The avatar shoots a knight. (d) Protection state of the avatar (e) A knight shoots the avatar (f) The avatar is protected from a bullet. All figures show the score (top left) and the lives remained (top right).

and has a clearer analysis approach from a statistical perspective (Lazar, Feng, & Hochheiser, 2017). In addition, a between-subjects design is suitable for our study because our participants execute the exact same task (i.e., playing the Extreme Yoga game) with the test condition (i.e., the interaction with the input modality, either gaze or mouse) as the only difference. Thus, we do not want children exposed to both input modalities, as they would become aware of the experiment's purpose (Hornbæk, 2013). Moreover, based on the fact that the study was conducted in real settings (a museum and a school), and depended on the voluntarily participation of the children, the time for the possible completion of tasks in both conditions may have been a problem for the smooth execution of a within-subjects study. Lastly, our task was simple, with small differences and the sample size was sufficient for a between subject design (Lazar et al., 2017).

Each subject was randomly assigned to one of the two conditions (i.e., gaze or mouse) to play the game (Fig. 2). Children received an explanation of the game and were allowed to try the game prior to their main gameplay. In particular, children were allowed to play for a while (most of the times they wanted/needed a minute or less) to become familiar with both the game and their gaze or mouse interaction modality. This is particularly important since none of the children had tried a gaze-based interaction game before. Tobii-4C eye-trackers with the sampling rate of 120 Hz were used with a 5point calibration and Tobii-4C's algorithm was used to detect the dwells on the avatar and the fixations on the knights. After the trial gameplay period, each child played on average 10 game-sessions, resulting in an average of approximately 6 min of gameplay. We did not control the number of game-sessions, and rather, allowed children to play as many times as they desired. This showed us their real engagement with the game and allowed for a scenario where they did not get additionally frustrated or stressed from having the game end, and only being permitted a fixed number of sessions. However, due to some limitations of our "in -situ" experiment, we controlled the maximum time the children were permitted to play (approximately 20 min), and the minimum time (approximately 3–5 min), to achieve a high-quality data. Since the game ended when all three lives were lost, the amount of time before "game over" depended on each child. Once a game ended, a child was given a few seconds reflection time, while the score was displayed. During this time, children were provided a unique ID to fill in on. At the end of the gameplay session, each child completed a post-questionnaire which provided information about their gameplay experience. Children took approximately 5 min to complete the questionnaire.

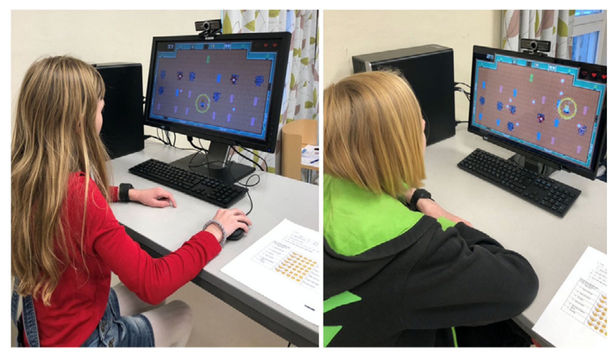

Fig. 2. Child playing the game using the mouse (left) and using the gaze (right).

3.3. Sampling

The study was conducted in Trondheim region, during Autumn 2019, and lasted for a three-week period. The study took place in a science museum and a local primary school. In both cases, the study was set up in a dedicated room and researchers were responsible for the smooth execution of the activities. Participants in our study were children who came as visitors in the science museum (15 children) and 6th grade students from a local primary school (42 children). Each child played alone at a dedicated station (Fig. 2). In total, 57 children (mean age: 10.58, S.D.: 1.38) from 3rd to 9th grade (age 8–14 years old) participated in our study. The sample for the gaze game condition consisted of 28 children (mean age: 10.00, S.D.: 2.78) of which 20 were boys and 8 were girls; the sample in the mouse game condition is consisted of 29 children (mean age: 10.75, S.D.: 0.95) of which 15 were boys. The two conditions had no significant difference between age and gender distribution. Researchers responsible for the study verbally informed the children, their parents and their teacher (in the school location) about the data collection process and the game. In addition, they provided a written information letter and consent form for legal guardians to sign. Both the child and the parent/legal guardian gave the assent/consent for the participation in the data collection and the whole process. Children started game play only after the consent form was signed. All participants were typically developing children with normal vision. The project was recommended by the 'NSD—The

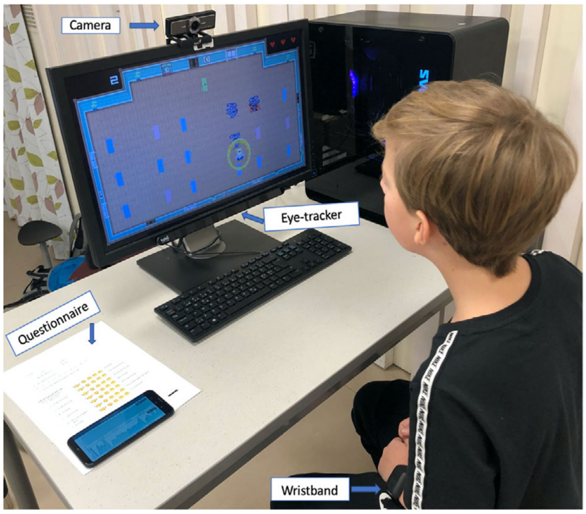

Fig. 3. Data collection set up showing a child playing the game with his gaze.

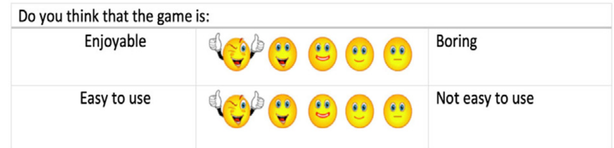

Fig. 4. Questions and emoticons used to measure children's experience.

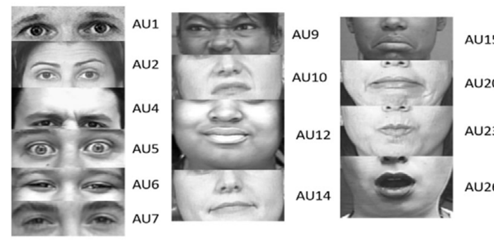

Fig. 5. Facial expressions depicting the respective Action Units (AUs) (Ekman et al., 2002; Tsai et al., 2012).

Norwegian Centre for Research Data AS" following all the regulations and recommendations for research with children. Lastly, children participated voluntarily and were able to withdraw their consent for the data collection at any time without affecting their participation in the activity.

3.4. Data collection

Before the experiment, we prepared two separate workstations in a room dedicated to the study (both at the museum or at school). First, the child sat on a chair facing a large computer monitor (see Fig. 3). The child was given a wristband and researchers calibrated the data collection devices (i.e., wristband, cameras). The researcher randomly selected one of the two conditions (mouse or gaze), explained the mechanisms of the game, double checked the data collection devices and initiated the respective game (mouse or gaze). When a child played the game in the gaze condition, the mouse was removed or set aside to avoid causing any confusion to the child (Fig. 3). None of the children had played a gaze-based game before.

With respect to the data collection, we captured participants' achieved scores for each game session and the number of sessions they played. In addition, we collected data from the following data sources.

Wristband Children were wearing the Empatica E4 wristband on their non-dominant hand. The wristband has four sensors recording the following four measurements (1) heart rate at 1 Hz (2) electrodermal activity (EDA) at 64 Hz (3) body temperature at 4 Hz (4) blood volume pulse at 4 Hz.

Questionnaire: At the end of the game children completed a paper-based post-questionnaire. Apart from demographics, the questions aimed to gain information regarding children's perceived experience. In particular, children were asked to rate their experience with the game regarding their enjoyment (Venkatesh, Speier, & Morris, 2002) and ease of use (Giannakos, 2013) (Fig. 4). In all measures, we used a five-point smileometer-like responses which are appropriate scales young children (Hall, Hume, & Tazzyman, 2016).

Video recording: We used a wide-angle Logitech Webcam to capture the children's facial expressions (for emotion detection) while playing the game. The web camera was zoomed at 150% into the children's faces and recorded video at 10 FPS.

Computer logs: Each action event was logged with a timestamp from the gameplay. We used the total number of sessions the child played and the achieved score.

Lastly, we carried out participant observations while children were playing the game in both conditions. These were used to complement our data and enhance our understanding while discussing the findings.

3.5. Measures

To investigate gaze interaction as an input modality to support children's gameplay, we investigated its difference from the traditional input modality of mouse (gaze or mouse as independent variable). To portray children's experience, we utilized various measures related to children's performance and perceptions, as well as their affective and behavioral processes. In particular, we used the following measures, perceived ease of use and enjoyment with the game; the score achieved in the game, the number of sessions played by the children, their stress, physiological arousal and the emotions of joy, sadness, surprise and emotional arousal (i.e., dependent variables). The overview of the measures used, their definitions and references in the literature, are presented in Table 1.

For the three emotions, we used the OpenFace framework (Amos, Ludwiczuk, & Satyanarayanan, 2016) to extract facial AUs (Ekman, Friesen, & Hager, 2002; Tsai, Lo, & Chen, 2012) (Fig. 5) from children's videos. The Facial Action Coding System (FACS) is a taxonomy for human facial movements as they appear on the face. Movement of individual facial muscles are encoded by FACS from slightly different instant changes in facial appearance. Using FACS enables the coding of nearly all anatomically possible emotions, through deconstruction into the specific AUs which produced the specific expression. This approach is common in the literature and has been successfully tested in relevant HCI and children contexts (Giannakos et al., 2020; Sharma et al., 2019).

3.6. Data analysis

Regarding the differences between the two conditions (mouse and gaze condition) with respect to the dependent variables

Table 1
Measurements considered in this study.

Dependent variable [Scale]	Data source	Definition and references
Ease of use (Gowases et al., 2008; Ramirez Gomez & Gellersen, 2019; Sibert & Jacob, 2000; Turner et al., 2014; Velloso & Carter, 2016)	Questionnaire	Represents the degree to which students believed that playing the game was easy (Giannakos, 2013; Tsai et al., 2012).
Enjoyment (Gowases et al., 2008; Ramirez Gomez & Gellersen, 2019; Sibert & Jacob, 2000; Turner et al., 2014; Velloso & Carter, 2016)		Represents the degree to which students believed that playing the game was enjoyable (Venkatesh et al., 2002).
Score	Computer logs	The child's game score.
Number of sessions		The number of games that a child played.
Stress [Celsius]	Wristband	Stress is computed as the decreasing slope of the child's body temperature. The more negative the slope of the temperature is in a given time window, the higher the stress is (Harada, 2002; Herborn et al., 2015).
Physiological Arousal [micro Simens]		Arousal is computed as increasing slope of the child's electrodermal activity (EDA). The more positive the slope of the EDA is in a given time window the higher the arousal is (Leiner, Fahr, & Früh, 2012).
Emotion-Joy	Webcam	Joy is computed using facial Action Units (AU) AU6 and AU10 (see Fig. 5) (Ekman et al., 2002; Sharma et al., 2019; Tsai et al., 2012).
Emotion-Surprise		Surprise is computed using AU1, AU4 and AU15 (see Fig. 5) (Ekman et al., 2002; Sharma et al., 2019; Tsai et al., 2012)
Emotion-Sadness		Sadness is computed using AU1, AU2, AU5 and AU26 (see Fig. 5) (Ekman et al., 2002; Sharma et al., 2019; Tsai et al., 2012)
Emotional arousal		Emotional physiological arousal is computed using the AUs for all six basic emotions (joy, sadness, anger, surprise, disgust, fear) (Cowie & Cornelius, 2003; Dalgleish & Power, 2000). where high arousal emotions (anger, fear, surprise, joy) contributed positively and the low arousal emotions (sadness, disgust) contributed negatively (Blanco-Ruiz, Sainz-de Baranda, Gutiérrez-Martín, Romero-Perales, & López-Ongil, 2020; Gunes & Pantic, 2010; Tkalčič, Burnik, Odić, Košir, & Tasič, 2012).

(Table 1), we performed a between group comparison using paired samples t-test. Where the normality test using Shapiro–Wilk (Royston, 1982) is not satisfied, a log transformation was performed (for score and anticipation).

Gender biases was checked using a paired samples t-test for boys and girls. Age bias was checked using Pearson correlations with the dependent variables (Table 1) in the two conditions respectively. When equal variance was not satisfied (for score), a Welch correction was performed (Welch, 1951). We also checked the correlations among all dependent variables to understand the relationships among them using Pearson correlation.

In the cases where we found bias due to gender or age, we further tested those relationships with independent variable (gaze vs. mouse). In addition, for certain post-hoc analysis, we used Spearman's rank correlation to test the relationship between the score and session ID (i.e., increasing number assigned as an ID to each game for every participant, to show progress).

4. Research findings

There were 15 boys and 14 girls participating in the mouse condition, while there were 20 boys and 8 girls in the gaze condition. Starting our analysis, we checked if there were any differences in our two conditions (mouse vs. gaze), children's age, gender, and the dependent variables. Results showed that there was no significant difference between the ages in the two conditions ($t = -1.38$, $p = 0.17$). We did not find any correlations between age and the dependent variables, except for the ease of use ($r = 0.33$, $p = 0.05$), score ($r = 0.26$, $p = 0.05$) and number of sessions ($r = 0.26$, $p = 0.05$). Further, it was found that the ease of use was significantly and positively correlated to the age in the gaze condition ($r = 0.38$, $p = 0.04$), while score (gaze condition: $r = 0.28$, $p = 0.15$; mouse condition: $r = 0.30$, $p = 0.10$) and number of sessions (gaze condition: $r = 0.28$, $p = 0.14$; mouse condition: $r = 0.17$, $p = 0.35$) were not significantly correlated with age for either of the two conditions. Since we found a relation between children's age and their perceived ease of use in the gaze condition, we performed a post hoc analysis which showed that the significance in correlation is only up to the age 9. This correlation does not exist beyond age 10 (see Fig. 6 left).

Concerning the children's gender, there was a difference in terms of the conditions and gender distribution (chi-sq $= 3.09$, $p = 0.21$). Regarding the bias of gender and the dependent variables, we did not find any gender-based difference for any of the variables except the game score. More specifically, we found that boys ($m = 112.67$, $sd = 74.14$) outperformed girls ($m = 79.05$, $sd = 51.27$) significantly ($t = 2.01$, $p = 0.05$).

Following on with our analysis, we examined whether there existed any expertise-based difference between the children who were assigned to the mouse and gaze conditions. We found no significant difference between the score (of the first four games) as the dependent variable and the condition (mouse vs. gaze) as independent variables ($F(1, 41.21) = 0.10$, $p = 0.74$, without the equal variance assumption). Also, we examined to see if there was any relation between children's experience with the game (i.e., ease of use and enjoyment, as reported from the subjective rating in the questionnaire) and their engagement (i.e., the

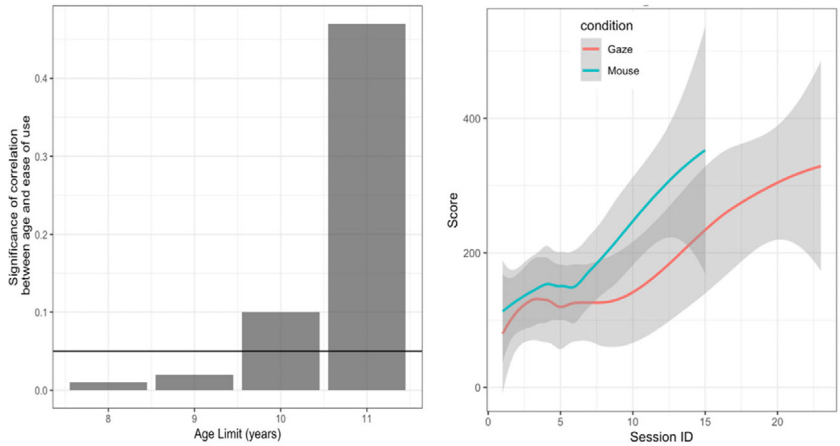

Fig. 6. Significance of correlation between age and ease of use, the horizontal line shows p = 0.05 (left). Score evolution for each condition over-time, the gray area shows the 95% confidence interval (right).

number of sessions they played from the computer logs). More specifically, we found no correlation between the number of sessions and enjoyment in the gaze condition ($r = -0.04$, $p = 0.86$), mouse condition ($r = 0.03$, $p = 0.87$) or overall ($r = -0.01$, $p = 0.91$). There was also no correlation between the number of sessions played and the ease of use in mouse condition ($r = 0.17$, $p = 0.34$). However, there was a significantly positive correlation between the number of sessions played and the ease of use in the gaze condition ($r = 0.45$, $p = 0.016$); but no significant correlation overall ($r = -0.01$, $p = 0.91$).

Further, we examined the differences between the dependent variables (see Table 1) across the two conditions (mouse vs. gaze). Starting with the results from the data coming from children's subjective rating answers in the self-reported questionnaire (i.e., perceived ease of use and enjoyment of the game), we found no significant differences in the two conditions (see Table 2). Children who played the game using the gaze-based interaction modality and the those who used the mouse, did not report different gameplay experience in terms of ease of use and enjoyment. This means that neither condition was perceived easier or more enjoyable compared to the other. Similarly, we found no significant differences in the two conditions based on the results from the analysis of computer log data (i.e., total number of sessions and the achieved score) (see Table 2). Therefore, children in the gaze and mouse condition demonstrated no difference in their engagement or their performance. Moreover, we also found a positive Spearman rank correlation between the session ID of the game (increases with every time a player restarts a game) and the score (Spearman correlation $= 0.45$, $p = 0.004$), showing that children improved over-time (see Fig. 6, right).

Despite the non-significant results in the analysis based on the data collected from the questionnaire and computer logs, regarding sensor data (i.e., wristbands and webcam), our analysis showed significant differences among the children who played the game using their gaze and the those using the mouse (see Table 2 and Fig. 7). More specifically, children during the gaze-based game interaction were less stressed and experienced higher physiological arousal from the gameplay, as shown by the physiological data. Furthermore, children expressed more joy, less sadness, more surprise and more emotional arousal in the gaze condition compared to the mouse condition. Although the highest levels of surprise in the gaze-based game interaction can be attributed to the unfamiliar interface element, overall, children playing with their gaze, had more positive experience during gameplay (less stress, higher physiological arousal, joy and emotional arousal) compared to playing with the mouse. This demonstrates that by using sensor data, we could identify differences in the children's experience from the two interaction conditions.

5. Discussion

In this study, we aimed to investigate the potential of using gaze input as an interaction modality during children's gameplay; something which to the best of our knowledge has not been previously examined. Accordingly, we developed and evaluated a shooting game which children could play using either a mouse or their gaze. Then, we performed a between subjects design study, and collected various multimodal data to capture children's experience during these two conditions. In particular during the gameplay, we collected children's facial videos, physiological data and click-streams, as well as their perceived experience through a post-questionnaire.

In general, our results show that gaze input can be considered as an interaction modality for children. There was no significant difference between the two modalities in children's perceived experience (ease of use and enjoyment). This is positive sign, since new input modalities usually receive worse feedback than traditional methods, due to users' unfamiliarity with the modality (Heidrich, Ziefle, Röcker, & Borchers, 2011), especially concerning the dimension of ease of use. The children who participated in our study had never encountered gaze-based interfaces before, and were accustomed to mouse interaction, which was expected to be perceived as easier. Other studies have found that gaze was more enjoyable than the mouse (Jimenez, Gutierrez, Latorre, & De Zaragoza, 2008; Smith & Graham, 2006) (coming from adult subjects) but O'Donovan et al. (2009) reported no statistically significant difference between mouse/keyboard and gaze/voice interaction in terms of users enjoyment with the game. In our results, we identified that ease of use was positively correlated with children's age in the gaze condition (not in the mouse condition), with the age of 10 being the turning point (as shown from the post-hoc analysis). Our observations during the gameplay confirmed this result since younger children had difficulty understanding the interaction with their gaze and this caused confusion. A very good example of this was the fact that *young children were trying to look somewhere without causing an action by moving their head instead of their eyes*. In general, taking into account all the participants, independent of the two conditions, the number of sessions that children played correlated with their age and ease of use, while score was also correlated with the age. Considering that older children perceived the gaze condition as easier; they were more engaged to play additional sessions and consequently scored higher. Although boys and girls played similar number of games, boys outperformed the girls in the game. This is not surprising as this is a recurrent finding when

Table 2
Testing the differences between the gaze and mouse condition using t-test.

Data Source	Variables	Gaze Condition		Mouse Condition		t-test results	
		Mean	sd	Mean	sd	T	p
Questionnaire	Ease of use	3.07	1.27	3.48	1.21	1.24	.21
	Enjoyment	4.21	1.13	3.65	1.31	1.71	.09
Computer logs	Score	109.33	88.2	90.2	39.77	1.02	.21
	# of sessions	11.14	6.13	12.1	6.36	0.59	.55
Wristband	Stress	0.35	0.26	0.50	0.23	2.13	.03*
	Physiological Arousal	0.53	0.24	0.33	0.26	2.52	.01*
Webcam	Joy	0.53	0.19	0.37	0.26	2.62	.01*
	Sadness	0.28	0.21	0.42	0.25	2.12	.03*
	Surprise	0.47	0.29	0.32	0.24	2.06	.04*
	Emotional arousal	0.63	0.17	0.40	0.21	6.31	.001*

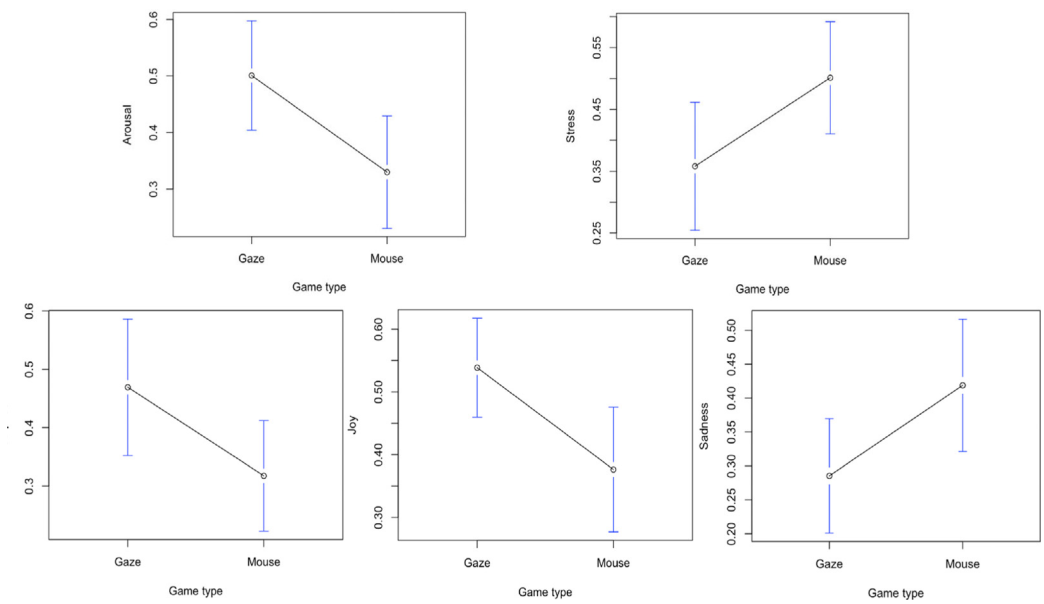

Fig. 7. The significant differences between mouse and gaze as input modalities to support children's gameplay, the blue bars in all the figures show the 95% confidence interval.

shooting is involved in the gameplay (Cherney & Poss, 2008; Hopp & Fisher, 2017).

Concerning the sensor data, results showed that sadness and stress were higher in the mouse condition; while joy, surprise, physiological arousal and emotional arousal were higher in the gaze condition. Specifically, we observed that arousal (physiological and emotional) was higher in the gaze condition; confirmed from both the physiological and webcam facial data. This may be related to the way emotions are aligned within our two conditions. For example, joy and surprise are both considered to be high arousal emotions (Blanco-Ruiz et al., 2020; Gunes & Pantic, 2010; Tkalčič et al., 2012) and are higher in the gaze condition whereas, sadness (considered as a low arousal emotion Blanco-Ruiz et al., 2020; Gunes & Pantic, 2010; Tkalčič et al., 2012) was higher in the mouse condition. Moreover, physiological arousal (as measured by EDA) has also been found to be related to different emotions in various studies (Harley, Jarrell, & Lajoie, 2019; Picard, Fedor, & Ayzenberg, 2016; Van Den Bosch, Salimpoor, & Zatorre, 2013). These findings show that children in the gaze condition had a more positive experience during their gameplay. Interestingly, joy as extracted from the children's facial expressions was significantly higher in the gaze condition and at the same time the results from the self-reported data show that enjoyment had no significant difference in the two conditions. Thus, using data from various sources might help us gain deep understanding and evaluate the results through different lenses. In another study, the players of a 3D flying game, considered the mouse interaction less physical and mental demanding (Nielsen, Petersen, & Hansen, 2012) but found interacting with the gaze to be more entertaining and engaging. Smith and Graham (2006), indicate that the gaze interaction is more enjoyable to use when playing a video game and that gaze also increases the player's level of immersion.

In our study, we found that children felt more surprised during the gaze condition, this can be explained from the fact that the children who participated in our study had never used gaze-based interfaces before. This result is similar to a previous study that investigated gaze interaction, and in which users reported the "magic" aspect that the cursor was following their intent (Zhai, Morimoto, & Ihde, 1999). Another interesting result is that children were more stressed when playing the mouse version of the game. Visual memory is short term and hence the effect of gaze feedback might cause less information processing than that of the mouse feedback (Orlov & Apraksin, 2015). Furthermore, from the literature on physiological data to measure stress while gaming, there are related constructs such as, comfort and confidence, which have been measured and support our finding (Orlov & Gorshkova, 2016).

5.1. Implications

In this study we present an experiment which demonstrates that using a child's gaze (8–14 years old) as a computer input modality is feasible. In particular, our study investigates gaze as an input modality when children play a computer game and is one of the first studies that compares gaze and mouse as interaction modalities for children, while using a wide range of multimodal data for the evaluation. Thus, in addition to the results of our study, our approach is an important contribution and provides implications for research and practice.

Regarding the research implications of this study, we would like to point out that the interest in MMD collection to assess children's experiences is growing (Sharma & Giannakos, 2020). This study uses several different types of MMD (click streams, physiological data, facial videos) from ubiquitous and contemporary devices, combined with subjective measures from self-reported questionnaire to gain a deep understanding of children's interaction with the game and overall experience. This is of particular importance since in our study no significant difference was identified when comparing data collected from the computer logs and the questionnaires (i.e., the typical quantitative data collections in HCI/CCI evaluations). However, data collected from sensors allowed us to identify some differences in children's experience between the mouse and the gaze condition (see Table 2). This sheds light on the usefulness of sensing technologies for CCI research. Nevertheless, from a practical perspective, conducting studies using sensing technologies with children requires more time for the appropriate preparation. Almost all of the children, parents and the teacher, were unfamiliar with the functionalities of the devices used and the kind of data collected, but all were informed through the consent form and the ethics for data collection beforehand. Nonetheless, standard consent forms are not enough. Prior to children's participation in a study using these sorts of devices and data collection, there is need for a child-friendly discussion to prepare and demonstrate device set up (in our case webcam, questionnaire, wristband) to the children, their parents and teachers. The children had many questions regarding the purpose and goals of each device, as well as the project. The researchers had to spend a considerable amount of time explaining and pointing out details of the research project and the value of the data. Also, we showcased the mobile device that displays the heart rate captured from the wristband in real time and explained gaze interaction to children. These were completely new experiences for the children, and they were very excited to try out the devices. In addition, researchers must be aware of possible discomfort that those devices might cause children during experiments and be prepared to take appropriate actions (e.g., remove the wristband), keeping also in mind that these are designed mainly for adults. Despite the challenges, however, their use is suitable for monitoring children's affective and behavioral processes.

Concerning practical and design implications, games for children can benefit from gaze as an input modality since such it is found to contribute to more positive gameplay experiences (e.g., lower stress, higher arousal). Gaze interaction during gameplay has several obvious advantages (e.g., children with motor impairments or other abilities) that increase the accessibility of those games. In addition, our study showed that gaze interaction has certain advantages for typically developed children, such as decreasing stress and increasing physiological arousal, compared the typical input device of mouse. This characteristic may help improve games for children with Attention Deficit Hyperactivity Disorder (ADHD) and Autism Spectrum Disorders (ASD), where keeping low stress levels are of paramount importance (Fuld, 2018). Gaze input could also be used for adaptive or embodied games in real time to decrease frustration in a significant challenge resulting in a better gameplay and learning experience for children (Kourakli et al., 2017; Wetzel, Spiel, & Bertel, 2014). Additionally, in terms of offering engaging experiences for children gaze-based interaction can be translated to the game world as an approach to social cooperative play, using gaze visualization (Maurer, Lankes, & Tscheligi, 2018). Leveraging this, social affordances in games through gaze can be useful to encourage and/or facilitate collaboration and sharing of emotions among children as players. Showing the partners' gaze by visualization on a shared interaction space can help when children are playing together and lead to efficient collaboration and task completion; for example, it can allow the distribution of different roles among players depending on their abilities and/or expertise.

Besides the typical benefits of gaze as an input modality, which we are aware from the HCI literature with adults as end-users (e.g., users are free to use their hands while interacting with their gaze, (Sibert & Jacob, 2000); our observations confirm that children expressed their emotions much more due to the fact that they were able to use their hands. These observations were confirmed from the analysis of children's emotions via the webcam facial data (see Table 2). Notably, gaze appears to be a promising interaction modality with many possibilities providing motivation for further investigation (e.g., different scenarios, mechanics, age groups). Giving joy is something that gaze input seems to support for children and thus, gaze can be employed to applications focusing on pleasant experiences, such as playing and to applications that are in need for avoiding stress and engaging students, as is the case with learning.

This study supports that gaze offers similar perceived experience and performance as mouse for children's game play (see computer logs and questionnaire results from Table 2). However, we identified that children younger than 10 years cannot use gaze an input modality as effectively. Gaze was found to be more adequate for middle childhood children and adolescences, since its use was easier for children 10 years and older. Early childhood children had difficulties understanding how to use their gaze properly, as we can see from their responses regarding the easiness of gaze interaction, and also from our observations (often younger children were confused and tried to move their head instead of their gaze). This might be connected with the fact that children's visual perception, motor skills and motor-perception coordination are not fully developed until the age of 10, which means that interactive controls and manipulations of objects should not put high demands on precision and speed (Markopoulos, Read, & Giannakos, 2021). CCI researchers and practitioners need to take this into account when deciding if and how to integrate gaze interactions in their technology or go with other interaction techniques and modalities that are more appropriate for these ages (e.g., physical manipulatives tablets interactions that can be effectively employed for very young children; Neumann & Neumann, 2014). Gaze interaction can offer other opportunities for interaction to younger children. Specifically in the context of educational games for children, Akkil et al. 2017 leveraged the richness of information that gaze can offer from an educational perspective and suggested a gaze aware agent. Therefore, in learning applications, by implicitly using information from gaze, a game specific function for example, can keep track of children's attention and provide proactive guidance (e.g., give a visual sign) or other specific feedback to the player to re-orient their attention in case of distraction.

Gaze alone might not be the optimal interaction modality for complex tasks which require a certain level of mastery and thus, children's developmental age (e.g., motor skills) need to be taken into consideration (Hourcade, 2015). A potential solution can be to use gaze in combination with other input interaction modalities. For example, gaze can be integrated in mobile games and when combined with voice, provides a stronger engaging interaction when compared to touch (Uludağli & Acartürk, 2018). Gaze, combined with handheld interaction (Stellmach & Dachselt, 2012) or mouse input seems to be another option, and might be able to support faster object selection, as well as children's experience. Nevertheless, we must consider the interplay of the affordances around gaze interaction (e.g., need for large displays and visual environments such as interactive screens in public spaces or museums), in order to support children's interaction with the machine. Games' interaction can be enhanced with gaze, for example, the games developed from Velloso, Oechsner, Sachmann, Wirth, and Gellersen (2015) for the famous arcade machines combining a full body interaction and other games enhanced from Tobii proving gaze experience. In general, eye-movements are an appealing and powerful input modality for computing machinery in various aspects (Jacob & Stellmach, 2016). Gaze-enabled games are changing the way we interact with games offering new opportunities for multiplayer games, games VR and AR devices that include eye-tracking (Lankes et al., 2018). Although such technologies exist, and we have seen their success with teenagers as end-users, future work needs to carefully explore under which conditions, age and developmental limits gaze interaction can be employed to support children's abilities.

Lastly, regarding the design of the games when implementing gaze-based interactions, it is advised to keep simple aesthetics, minimalistic design and minimize memory load by making actions visible and allowing children to become familiar with the interactive objects of the interface faster. We observed this difference, during children's gameplay, since the mouse allowed them to explore the screen faster, while with gaze the children had to first identify the gaze interactions, and this made additional exploration more demanding. Therefore, gaze interaction was found to be an interesting interaction modality for children's gameplay, especially when (based on our observations) the intended actions are simple and explicit.

5.2. Limitations and future work

The present study is one of the first of its kind to explore gaze interaction to support children's gameplay utilizing MMD. However, our study entails some limitations. First, the design of the game is simple, both in terms of graphics and functionality. Having a different game genre, game design or gaze interaction mechanics could have affected the results. For the gaze interactions, we selected simple interaction (e.g., fixation position and fixation duration). Alternatively, we could have used other mechanisms (e.g., blinking). However, since this is one of the seminal works in gaze interaction for children's gameplay, we decided to first investigate simple mechanics. Adding and testing additional or different gaze mechanics as input might affect the results; however, such an endeavor requires a deeper exploration and the conduction of a series of studies. The children who participated in our study had never tried a gaze-based interaction before. Although we provided them with an opportunity to familiarize themselves with the game interface and gaze as an input modality prior to their main gameplay, we recognize that their inexperience with this interaction mode might have affected their gameplay and perceptions. Novelty may play a role in children's experience with gaze-based interactions; children may become more engaged with technology when they perceive it as novel and could become less engaged over time (Jeno, Vandvik, Eliassen, & Grytnes, 2019; Koch, von Luck, Schwarzer, & Draheim, 2018; Leite, Martinho, Pereira, & Paiva, 2009; Tsay, Kofinas, Trivedi, & Yang, 2020). Moreover, visualization plays a role in gaze interaction and our choice could have influenced how the game was perceived by the children.

Another important limitation of this study is the fact that it was mainly based on quantitative data. Although the researchers observed children's gameplay and overall behavior to enrich their understanding of the results, the collection of structured qualitative data (e.g., observations and interviews), would have helped us in getting additional insights about children's experience. In addition, while there has been a significant amount of research that uses automated systems to identify emotions based on facial expressions, this approach used in this study is not without controversy (Barrett, Adolphs, Marsella, Martinez, & Pollak, 2019; Heaven, 2020). Lastly, the selection of the measurements used as dependent variables in our study is grounded in the literature and those measurements have been widely applied before. However, we also acknowledge that different selection of measurements could have been made and this would have shifted the focus of the investigation on slightly different aspects.

This study opens up interesting perspectives for future research by introducing gaze interaction for children's gameplay as an interesting interaction modality. Our initial evaluation can be used as a springboard for future studies to further investigate age appropriation of the various gaze interactions, contexts and contents and open new prospect on supporting children's gameplay. One concrete recommendation for future work is to explore the potential of leveraging on "more complex" mechanisms of gaze-based input (e.g., blinks or dwell time) with children or gaze-augmented input (e.g., gaze and head movement) to support children's gameplay. Introducing different input modalities, investigating the differences among them and comparing them (or their confluence) with more traditional inputs like the mouse and touch, will open new avenues in games design for children. For example, an idea is to compare gaze with touch input in different contexts, like games or other applications in mobile devices. In the future, different type of games can test the possibility to use gaze interaction. For example, educational games, puzzles, point and collect. Regarding the use of MMD, we believe that we can benefit from its affordances (e.g., access to momentary experience and affective processes of children) and future studies can perform more granular analysis (e.g., temporal analysis) to portray different aspects of children's experience and experiment with different methods (Papamitsiou, Pappas, Sharma, & Giannakos, 2020; Pappas & Woodside, 2021).

6. Conclusion

In this study we investigated the use of gaze interaction to support children's gameplay. We developed a game that enabled gaze as an input modality and performed a between subject's research design study with children testing gaze and mouse as interaction modalities. During children's gameplay, we captured their affective and behavioral processes with the use of MMD, attitudes and performance utilizing a post-questionnaire and system's logs. Our results show no significant difference on children's ease of use and enjoyment among the two interaction modalities. However, the actual usage and children's physiological data showed that sadness and stress are higher in the mouse condition while joy, surprise, physiological arousal and emotional arousal are higher in the gaze condition. Furthermore, our findings, stress the benefits of using MMD to reveal children's behavior during gameplay. We provide implications for practice and research and show the need for more studies to explore gaze as an input modality.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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